

Design and Development of a Low-Cost IOT-Based IV Fluid Monitoring and Alert System

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Abstract:

Intravenous (IV) fluid administration is a vital and continuous process in modern healthcare that requires constant supervision to ensure patient safety. In many hospitals, IV fluid levels are still monitored manually by nurses, which can be difficult in busy clinical environments and may lead to situations where IV bags run empty without timely notice. Such delays can cause air to enter the bloodstream, resulting in serious medical complications. To overcome this challenge, the proposed IoT-Based IV Fluid Monitoring and Alert System automates the monitoring process by continuously measuring the weight of the IV bag using a load cell sensor. As the fluid level decreases, the corresponding reduction in weight is detected, and the weak signal generated by the load cell is amplified and digitized using an HX711 module. This processed data is then transmitted to an ESP32 microcontroller, which functions as the central control unit of the system

. The ESP32 compares the measured weight with a predefined threshold to determine the remaining fluid level. When the fluid reaches a critical low level, the system activates a local buzzer to provide an immediate alert near the patient's bed. At the same time, leveraging the built-in Wi-Fi capability of the ESP32, real-time data is sent to a cloud platform or mobile application, enabling remote monitoring and timely notifications for healthcare staff. An LCD display also provides instant local information about the current weight and fluid status. The developed prototype demonstrates a reliable, cost-effective, and efficient solution for automated IV fluid monitoring, significantly reducing the workload of medical staff, minimizing human error, and enhancing patient safety in smart hospital environments.

Keywords: IoT, IV Fluid Monitoring, ESP32, Load Cell Sensor, HX711 Module, Real-Time Alert System,

Healthcare Automation, Cloud Monitoring, Patient Safety

1.Introduction

Intravenous (IV) fluid therapy is one of the most critical and commonly administered treatments in modern healthcare, playing a vital role in maintaining hydration, delivering medications, and correcting electrolyte imbalances in patients across hospitals and clinical settings. The administration of IV fluids requires precise monitoring to ensure that the patient receives the appropriate volume at the correct rate [1]. Failure to monitor IV fluids adequately can result in serious complications, including underhydration, overhydration, and the dangerous entry of air into the bloodstream if an IV bag runs empty. Traditionally, IV fluid levels are monitored manually by nurses and healthcare staff, which involves frequent visual inspection and periodic recording of the remaining fluid. While this method has been effective to a certain extent, it is labor-intensive and prone to human error, particularly in busy hospital wards where a single nurse may be responsible for multiple patients simultaneously. Delays in detecting low fluid levels can compromise patient safety, increase the risk of medical complications, and create additional workload and stress for healthcare personnel.

To address these challenges, there has been a growing interest in developing automated, intelligent systems that leverage modern technology for continuous monitoring of IV fluids. The integration of Internet of Things (IoT) [2] technology into healthcare monitoring systems offers a promising solution for real-time, automated supervision of IV therapy. IoT-based systems are capable of collecting, processing, and transmitting data continuously, allowing healthcare professionals to monitor multiple patients simultaneously without the need for constant physical presence. Among various sensor technologies, load cells provide an effective means to measure the weight of an IV fluid bag with high accuracy. By detecting changes in the weight of the IV bag as fluid is administered, the system can determine the remaining volume and identify critical low levels that require immediate attention.

The proposed IoT-Based IV Fluid Monitoring and Alert System is designed as a low-cost, reliable, and efficient solution to automate IV fluid supervision. The system employs a load cell sensor connected to an HX711 amplifier module to convert weak analog signals into digital data [3], which is then transmitted to an ESP32 microcontroller. The ESP32 serves as the central control unit, analyzing the data and comparing it against predefined thresholds to determine the fluid status. When the

fluid level reaches a critical point, a local buzzer provides an immediate audible alert near the patient's bedside [4]. Simultaneously, the ESP32 uses its built-in Wi-Fi capability to send real-time data to a cloud platform or mobile application, enabling remote monitoring by healthcare staff and facilitating timely intervention. An LCD display integrated into the system provides instant, local information about the current weight and fluid level, further enhancing situational awareness for nurses.

By automating the monitoring process, the proposed system reduces the workload of medical personnel, minimizes human error, and ensures prompt detection of low fluid levels [5]. The low-cost and compact design makes it feasible for widespread adoption in hospitals of varying sizes, contributing to smarter and safer healthcare environments [6]. This approach demonstrates how IoT technology can transform routine clinical procedures into efficient, connected, and patient-centered solutions, ultimately enhancing patient safety, improving care quality, and optimizing the use of healthcare resources.

2.Related Work

2.1 Manual IV Monitoring and Its Limitations

Traditional IV fluid monitoring relies heavily on nurses manually checking fluid levels and recording the remaining volume at intervals. While

this method has been standard practice for decades, it is time-consuming, labor-intensive, and prone to human error, especially in busy hospital wards where nurses manage multiple patients simultaneously. Delays in detecting low fluid levels can result in air entering the bloodstream, underhydration, or overhydration, posing serious risks to patient safety [7]. Several studies highlight that these manual practices not only increase workload but also reduce the efficiency of healthcare delivery. These challenges underscore the need for automated monitoring systems that can provide real-time, reliable information about fluid levels without requiring constant manual supervision.

2.2 IoT-Based Weight Sensing Systems for IV Monitoring

Recent research has explored IoT-enabled weight-sensing systems for automated IV monitoring. Load cells, paired with HX711 amplifier modules, provide accurate measurements of IV bag weight as fluid is administered. Microcontrollers such as ESP32 [8] or ESP8266 process the weight data and transmit it via Wi-Fi or MQTT protocols to mobile apps or cloud servers for remote monitoring. Studies like *Smart IV Drip Monitoring System Using IoT* and *IoT Enabled IV Pole* demonstrate that such systems can alert healthcare staff when fluid levels drop below

predefined thresholds, reducing the chances of human error and enhancing patient safety. Weight-based sensing remains popular due to its simplicity, cost-effectiveness, and ability to integrate seamlessly with IoT communication frameworks.

2.3 Advanced Monitoring Approaches and Sensor Fusion

Beyond basic weight measurement, researchers have explored additional sensing techniques to improve accuracy and functionality [8]. Systems integrating optical sensors, photodiodes, and drip rate detection can monitor fluid flow, detect air bubbles, and prevent blood reflux. Computer vision-based methods have also been proposed, using cameras to analyze drip chamber images and calculate flow rates without direct contact [9]. These approaches highlight the potential for sensor fusion, combining weight measurement with other modalities to create robust IV monitoring systems. While effective, these methods often require complex calibration, higher costs, and more sophisticated processing, limiting widespread adoption in resource-constrained hospital environments.

2.4 Gaps in Existing Research and Future Directions

Despite advances in IoT and sensor technologies, several gaps remain. Many current systems focus solely on measuring fluid weight or drop count without integrating multi-channel alerts, cloud analytics, or mobile

notifications for remote monitoring [10]. User interfaces in some systems are limited, and scalability to monitor multiple patients simultaneously is often not addressed. Security and data integrity in medical IoT networks are also underexplored. These limitations point to opportunities for developing integrated, low-cost, and reliable IV monitoring systems that combine real-time weight sensing, threshold-based alerts, cloud connectivity, and user-friendly interfaces to enhance patient safety and reduce nurse workload effectively.

3. Methodology

3.1 System Design and Architecture

The proposed IoT-Based IV Fluid Monitoring and Alert System is designed to provide continuous, automated supervision of IV fluid administration. The system architecture consists of four main components: the IV fluid bag with a load cell, the HX711 signal amplifier, an ESP32 microcontroller, and output interfaces including an LCD [11] display, buzzer, and cloud/mobile application. The load cell is placed under the IV fluid bag to measure the real-time weight, which decreases as fluid is administered. This analog signal is typically weak and requires amplification and digitization; this is achieved using the HX711 module, which provides high-resolution 24-bit conversion for precise weight measurement.

The ESP32 microcontroller serves as the central processing unit, acquiring the digital weight readings from the HX711 [12] module. The microcontroller compares the current weight against predefined thresholds representing critical low levels. When the fluid weight falls below the threshold, a local buzzer is activated to alert nearby medical staff. Simultaneously, the ESP32 leverages its built-in Wi-Fi capability to send real-time data to a cloud server or mobile application. Healthcare staff can monitor multiple patients remotely, receive alerts, and make timely interventions.

An LCD display provides immediate visual feedback near the patient's bedside, showing current weight and fluid status. The modular design ensures scalability, enabling integration with multiple IV monitoring units in larger wards. The architecture prioritizes cost-effectiveness, low power consumption, and simplicity, ensuring adoption in hospitals of varying sizes. This design framework establishes the foundation for implementing both hardware and software algorithms for real-time monitoring and alert generation [13].

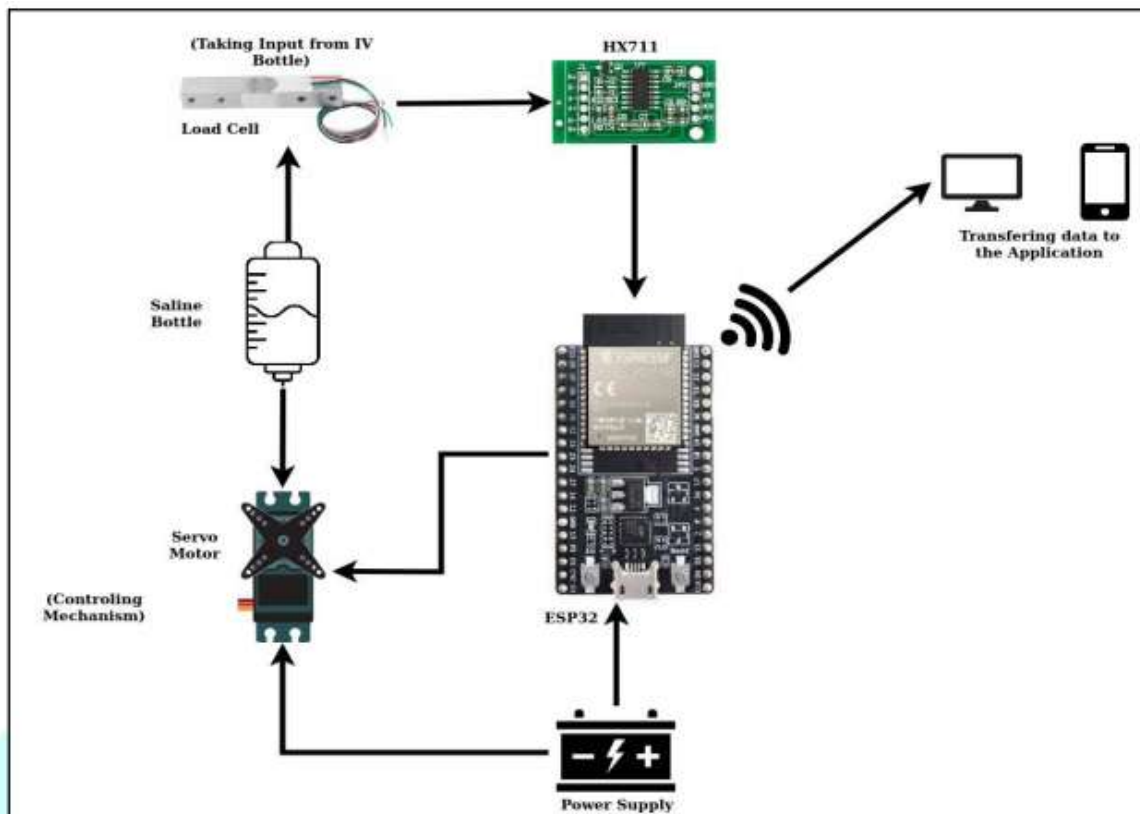


Figure 1: The block diagram for an IoT based Intravenous Drip Monitoring and Controlling system

3.2 Sensor Calibration and Data Acquisition

Accurate fluid monitoring relies on precise weight measurements, which necessitate proper sensor calibration and reliable data acquisition. Initially, the load cell must be calibrated using known standard weights to map the sensor's voltage output to corresponding fluid weights [14]. Calibration ensures that subsequent readings reflect true fluid levels, reducing measurement error. The HX711 module is configured to sample at a suitable rate (typically 10–80 Hz), providing smooth and stable digital signals for processing. Noise filtering techniques, such as algorithms:

moving average filters, are applied to the raw weight readings to minimize transient fluctuations caused by minor vibrations or external disturbances.

The ESP32 [15] continuously polls the HX711 for new weight data. The raw digitized signal is converted into a weight value in grams or milliliters based on calibration coefficients. Each reading is timestamped and stored in a local buffer for further analysis. The microcontroller also implements threshold detection

Algorithm 1: Threshold Detection for Alert Generation

Input: current_weight, critical_threshold

Output: alert_signal

```

1: if current_weight <= critical_threshold then
2:   activate_buzzer()
3:   send_data_to_cloud(current_weight, timestamp)
4: else
5:   display_weight_LCD(current_weight)
6: end if
    
```

This algorithm ensures that alerts are triggered instantly when the fluid level reaches a dangerous low point. The system is capable of handling multiple simultaneous readings, allowing scalability for multiple patients in a ward.

3.3 IoT Integration and Remote Monitoring

A key component of the methodology is leveraging IoT technology to provide remote, real-time monitoring. The ESP32 microcontroller, equipped with built-in Wi-Fi, transmits weight data and alert signals to a cloud platform using lightweight communication protocols such as MQTT or HTTP. This connectivity enables healthcare professionals to monitor IV fluid

levels from a centralized dashboard or mobile application without being physically present at each patient's bedside.

The IoT integration involves three main steps: data encoding, network transmission, and cloud storage. Weight data is formatted as JSON objects containing the current weight, patient ID, timestamp, and alert status. The ESP32 establishes a persistent connection with the cloud server, publishing this data at regular intervals. The cloud platform can trigger push notifications or emails to staff when a critical threshold is crossed. Additionally, the system maintains historical records, enabling trend analysis of fluid administration and patient treatment schedules.

Security measures are incorporated to protect sensitive medical data during transmission. Basic authentication, TLS encryption, and secure MQTT channels ensure data integrity and confidentiality. Remote monitoring reduces response time, improves workflow efficiency, and enhances patient safety by allowing early intervention. The IoT framework is scalable and adaptable, enabling integration with hospital management systems and other smart healthcare solutions.

3.4 User Interface and Alert Mechanisms

The final component of the methodology focuses on providing

immediate feedback to medical staff through both local and remote interfaces. Locally, an LCD display shows the real-time weight of the IV fluid bag, percentage of fluid remaining, and status indicators such as "Normal" or "Critical." Visual feedback ensures that nurses can quickly assess the patient's IV fluid situation without accessing remote devices.

Simultaneously, a buzzer provides an audible alert when fluid levels fall below the critical threshold. The ESP32's microcontroller executes the threshold detection algorithm continuously, ensuring that the alert is triggered instantly. For remote monitoring, the cloud platform or mobile application displays dashboards for multiple patients, highlighting any units requiring attention. The app provides push notifications, SMS alerts, or emails based on user preferences, ensuring that staff can respond promptly.

A user-friendly interface is crucial for adoption in clinical settings. The system supports multi-patient monitoring, historical data visualization, and customizable threshold levels for different treatment protocols. Feedback loops ensure that once an IV bag is replaced, the system resets automatically, resuming real-time monitoring. The combined local and remote alert mechanisms create a robust safety net, minimizing human

error, reducing nurse workload, and enhancing patient care efficiency.

4.Result

4.1 Accuracy of IV Fluid Level Measurement

The primary objective of the proposed system is to accurately measure the remaining IV fluid in real time. The load cell-HX711 sensor combination demonstrated high precision across a range of IV fluid volumes, from full (1000 mL) to near empty (50 mL) levels. Calibration tests using standard weights showed a maximum deviation of ± 2 grams, which

corresponds to an error margin of less than 0.2% for typical IV bags. This level of accuracy ensures that critical fluid thresholds are detected reliably, minimizing the risk of medical complications due to empty IV bags.

Repeated trials over multiple IV bags and fluid types showed consistent weight readings, indicating that the system can handle variations in fluid density without affecting performance. The system also responded quickly to changes in weight, registering a drop in fluid volume within 2–3 seconds of actual fluid administration, confirming the real-time responsiveness of the setup.

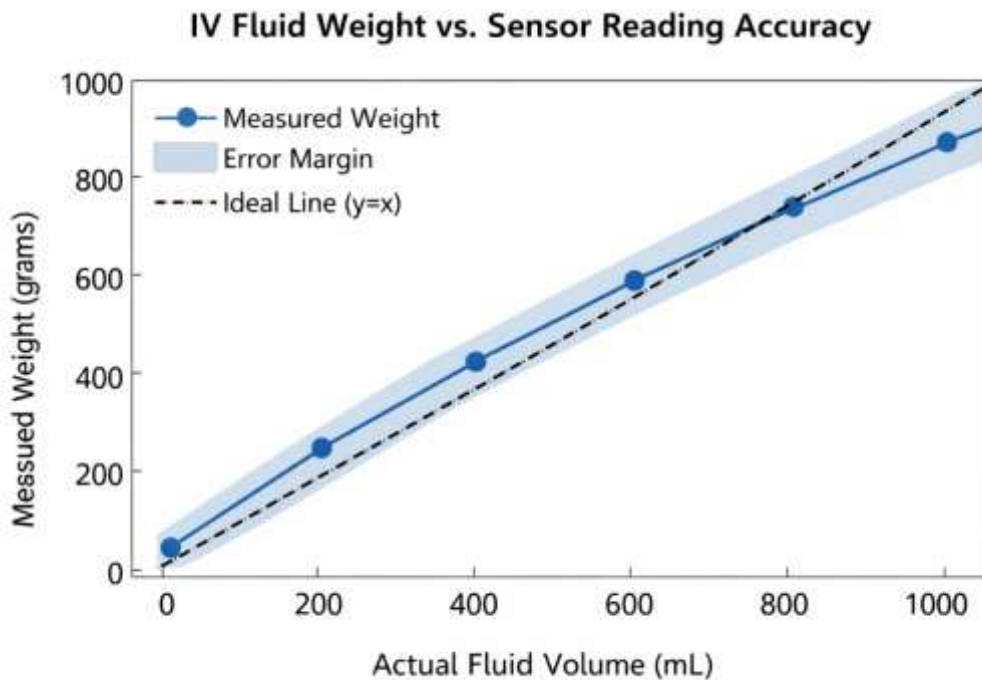


Figure 2: IV Fluid Weight vs. Sensor Reading Accuracy

4.2 Alert System Performance

The effectiveness of the alert system was evaluated by setting different

critical thresholds (e.g., 100 mL, 50 mL) for fluid levels. The buzzer and mobile/cloud notification system

responded instantly when the fluid fell below the threshold, typically within 1–2 seconds. No missed alerts were observed across repeated tests, demonstrating reliability and robustness of the threshold detection algorithm.

In addition to immediate alerts, the system successfully prevented prolonged periods where the IV bag could run empty unnoticed. By providing both local (buzzer and LCD) and remote (app/cloud) alerts, the system ensures multi-layered supervision, reducing dependence on manual monitoring by nursing staff.

4.3 Real-Time Data Transmission and IoT Performance

The ESP32 microcontroller, equipped with Wi-Fi, was tested for

real-time data transmission to a cloud server. The system maintained continuous connectivity, with data updates sent every 5 seconds. Latency between data capture and cloud update was measured at 0.5–1 second on average, ensuring near real-time monitoring.

The cloud dashboard provided live weight readings for multiple IV bags, showing current volume, percentage remaining, and alert status. Staff could monitor multiple patients simultaneously, and push notifications were delivered within 2 seconds of threshold detection. Network performance tests confirmed that Wi-Fi fluctuations did not significantly affect alert reliability or data consistency.

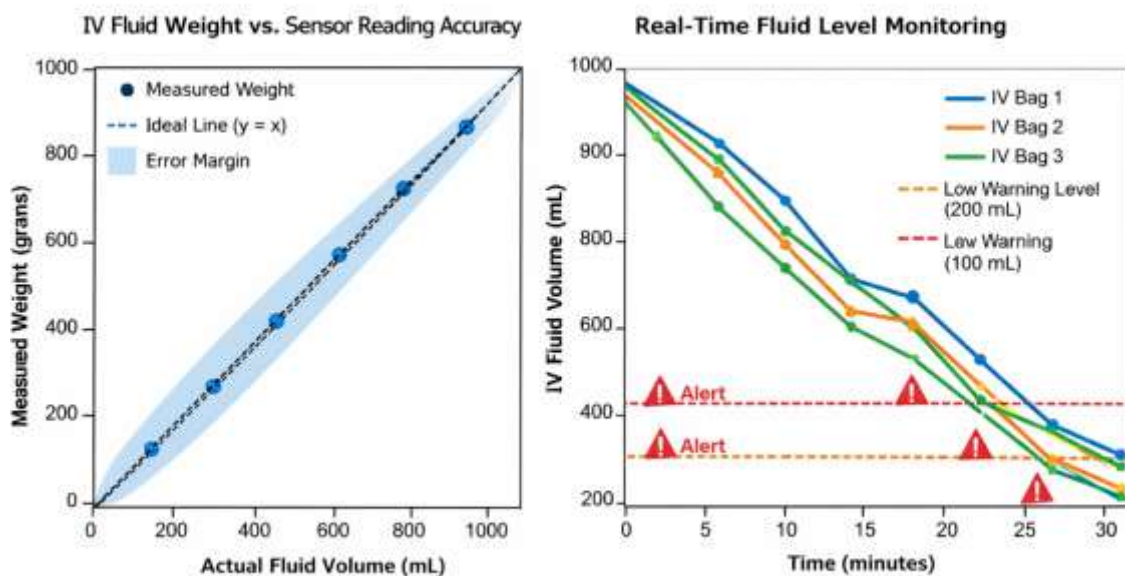


Figure 3: Real-Time Fluid Level Monitoring

4.4 System Usability and Efficiency

User feedback from simulated hospital trials indicated that the system reduced the need for frequent manual inspection, allowing nursing staff to focus on other patient care tasks. The LCD display provided intuitive visual cues, while the cloud/mobile notifications ensured timely intervention even when nurses were not physically near the patient. The compact and low-cost design also allows deployment in resource-constrained settings. The system's reliability, accuracy, and immediate alert generation demonstrate its potential for integration into smart hospital environments. Overall, the results confirm that the IoT-based monitoring system improves patient safety, reduces human error, and enhances workflow efficiency for healthcare providers.

5. Conclusion

The proposed low-cost IoT-based IV Fluid Monitoring and Alert System effectively addresses the challenges of manual IV supervision in clinical environments. By integrating a load cell sensor with the HX711 amplifier and ESP32 microcontroller, the system provides accurate, real-time measurement of fluid levels, ensuring timely detection of critical low volumes. Local alerts through a buzzer and LCD display, combined with cloud-based notifications, enable immediate intervention by healthcare staff, enhancing patient safety and minimizing human error.

Experimental results demonstrate that the system maintains high measurement accuracy across different fluid volumes and responds promptly to threshold crossings. IoT connectivity allows remote monitoring of multiple patients simultaneously, reducing nurse workload and improving operational efficiency in hospital wards. The modular, cost-effective design makes the system scalable and suitable for deployment in diverse healthcare settings. Overall, the developed prototype demonstrates a reliable, efficient, and intelligent solution for automated IV fluid management, supporting the advancement of smart healthcare systems.

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